DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY
RESEARCH REPORT

Dynamic Test of a Slipformed Concrete Barrier Type 50 Placed Over Lowered Existing Cable Barrier

74-36

FINAL REPORT
CA-DOT-TL-6696-1-74-36
DECEMBER 1974

Prepared in Cooperation with the U.S. Department of Transportation,
Federal Highway Administration

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

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TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE	
Dynamic Test of a Slipformed Concrete Barrier Type 50 Placed Over Lowered Existing Cable Barrier	5. REPORT DATE: December 1974 6. PERFORMING ORGANIZATION CODE: 19601-762501-656696
7. AUTHOR(S): Nordlin, E. F.; Juergens, W. R.; Tye, E. J.; Stoker, J.R.; Stoughton, R.L.; Parks, D. M.	8. PERFORMING ORGANIZATION REPORT NO.: CA-DOT-TL-6696-1-74-36
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Transportation Laboratory, Division of Construction and Research, Sacramento, California 95819	10. WORK UNIT NO.: 11. CONTRACT OR GRANT NO.: D-4-130
12. SPONSORING AGENCY NAME AND ADDRESS: California Department of Transportation, Division of Construction and Research, Sacramento, California 95807	13. TYPE OF REPORT & PERIOD COVERED: Final Report 14. SPONSORING AGENCY CODE:

15. SUPPLEMENTARY NOTES

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration.

16. ABSTRACT

One vehicular impact test was conducted to determine whether a New Jersey shaped concrete median barrier slipformed over a lowered cable median barrier was equivalent in structural strength and stability to Concrete Barrier Type 50 already tested successfully and accepted for use on California highways. A 4860 lb. (2204 kgf) vehicle, impacting at 68 mph (109 km/hr) and 27°, remained stable during and after redirection by the contoured face of the concrete test barrier. There was no significant barrier movement or damage. The construction method used for this test barrier is now permitted as an alternate method for constructing Concrete Barrier Type 50 in medians where cable barrier is being replaced by concrete barrier. This alternate construction method allows contractors to cut existing cable barrier posts off 1'-0" (0.31m) above grade, to remount one existing 3/4" (19.1mm) diameter cable on the post stubs, and to slipform the concrete barrier over the cable and post stubs, thus eliminating the 10" (254mm) deep concrete footing normally required for Concrete Barrier Type 50.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Cable median barriers, deceleration, dynamic tests, impact tests, median barrier, slipforming construction, vehicle dynamics	Unlimited

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	34	

HMRT 1242 ORIG 9/72

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY

December 1974

FHWA No. D-4-130
TL No. 656696

Mr. R. J. Datel
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

DYNAMIC TEST OF A
SLIPFORMED CONCRETE BARRIER TYPE 50 PLACED OVER
LOWERED EXISTING CABLE BARRIER

Study made by.....................Structural Materials Section

Under the Supervision of..........E. F. Nordlin, W. R. Juergens

Principal Investigator............E. J. Tye

Co-Principal Investigators........J. R. Stoker, R. L. Stoughton

Research Assistant................D. M. Parks

Very truly yours,

JOHN L. BEATON
Chief Engineer, Transportation Laboratory

Attachment

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ACKNOWLEDGEMENTS

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, as Item D-4-130 of Work Program HPR-1(11) Part 2, Research, and was titled, "Dynamic Test of a Slipformed Concrete Barrier Type 50 Placed Over Lowered Existing Cable Barrier". The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. It should also be recognized that the opinions, findings, and conclusions expressed in this publication are not necessarily those of the Federal Highway Administration.

Appreciation is due the following staff members of the Transportation Laboratory who were instrumental in the successful completion of this test:

Lee Staus	In charge of: preparation and operation of the test vehicle and other test equipment
James Keesling Roger Pelkey Lee Wilson	Assistance with: test, data reduction, and preparation of report.
Robert Mortensen Lewis Green	Data and documentary photography
Richard Johnson Stanley Law Delmar Gans	Instrumentation of test barrier, vehicle and dummy

Appreciation is also due R. P. Hackett of the California Division of Highways Structures Maintenance Branch who served as a consultant on this project.

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I. INTRODUCTION

Between the years 1971 and 1973, 192 miles (309 km) of Concrete Barrier Type 50, with the New Jersey profile, were constructed on California highways. This median barrier was approved for use in California after conducting successful dynamic tests on a cast-in-place unreinforced concrete barrier in 1967[1]* and after evaluating experimental in-service barrier sections of this same barrier in 1968 and 1969.

In 1972, a special construction method was approved on a trial basis for a limited number of contracts in California to replace existing cable barrier, Figures 1 and 2, in medians with a modified Concrete Barrier Type 50, Figure 3. Contractors were allowed to cut existing cable barrier posts off 1'-0" (0.305m) above grade, to remount one existing cable on the post stubs, salvaging the second cable, and to slipform the concrete barrier on top of the median surface over the cable and post stubs. The anchorage provided by the embedded lowered cable and steel post stubs eliminated the need for the continuous 10 inch (254mm) deep concrete footing normally required for Concrete Barrier Type 50, Figure 4.

Approximately 200 miles (322 km) of cable barrier in narrower medians in California are subject for replacement by Concrete Barrier Type 50. By the end of 1972 about 20 miles (32 km) of cable barrier were replaced by concrete barrier using this special construction method. On two such projects in the Los Angeles area in 1972 total savings were $0.94 per lineal foot for 18,730 ft. (5713m) and $1.50 per lineal foot for 20,000 ft. (6100m) of this modified Concrete Barrier Type 50. These savings were obtained through cost incentive contract change orders which provide that one half the above savings reverts to the State.

Following the preliminary acceptance of this construction method a full scale dynamic proof test was conducted on this barrier. It was desired to verify whether a modified Concrete Barrier Type 50 slipformed over a lowered cable barrier could be considered equivalent in structural strength and stability to Concrete Barrier Type 50 with a footing, already successfully tested. Also, if the test proved successful, this alternate construction method could be shown on contract drawings. Contract change orders would be eliminated on future projects, thus the state would gain the full cost savings rather than the 50% allowed through the cost incentive program.

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*Numbers in parentheses refer to a reference list at the end of the report.

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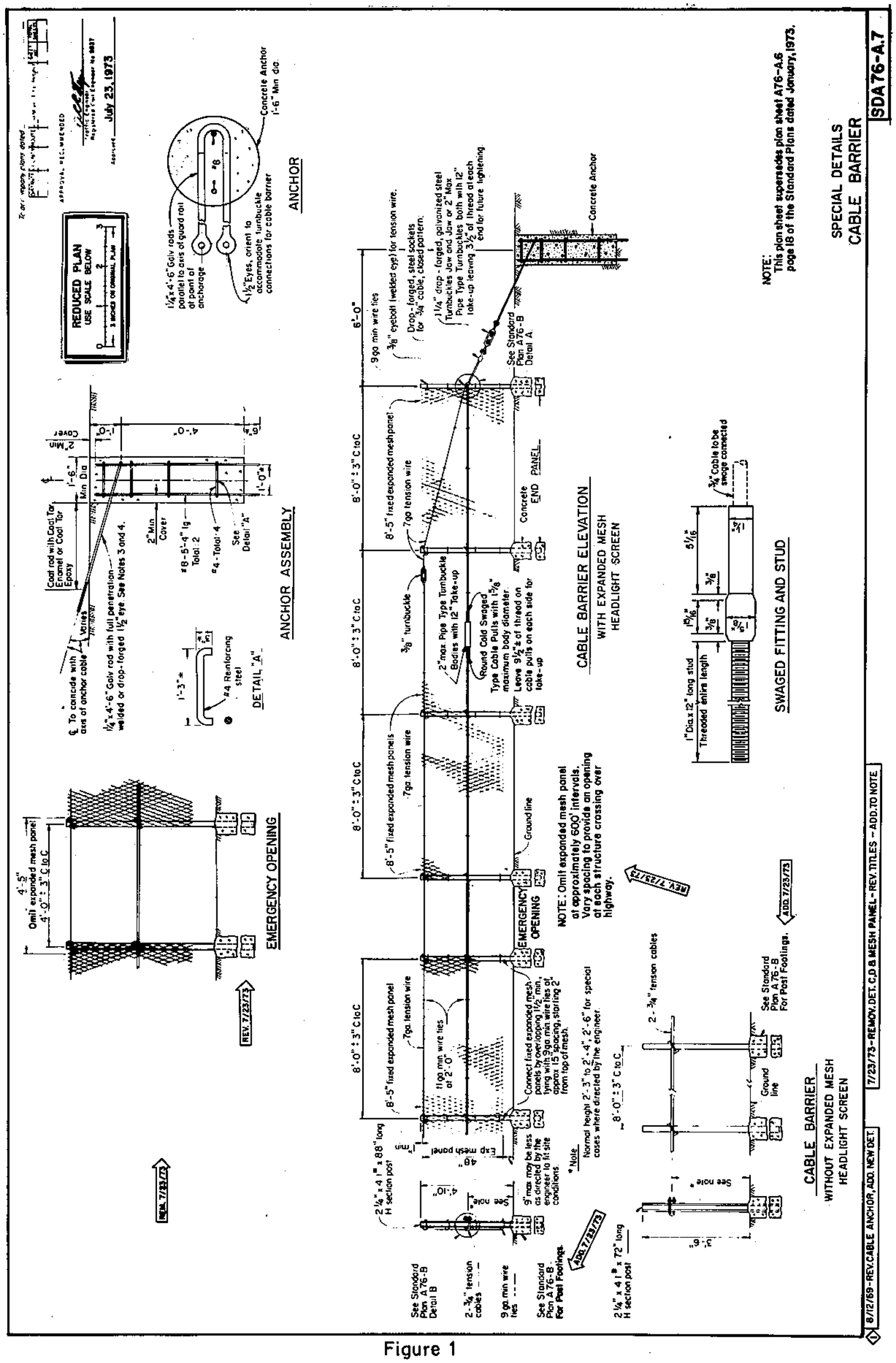

Figure 1

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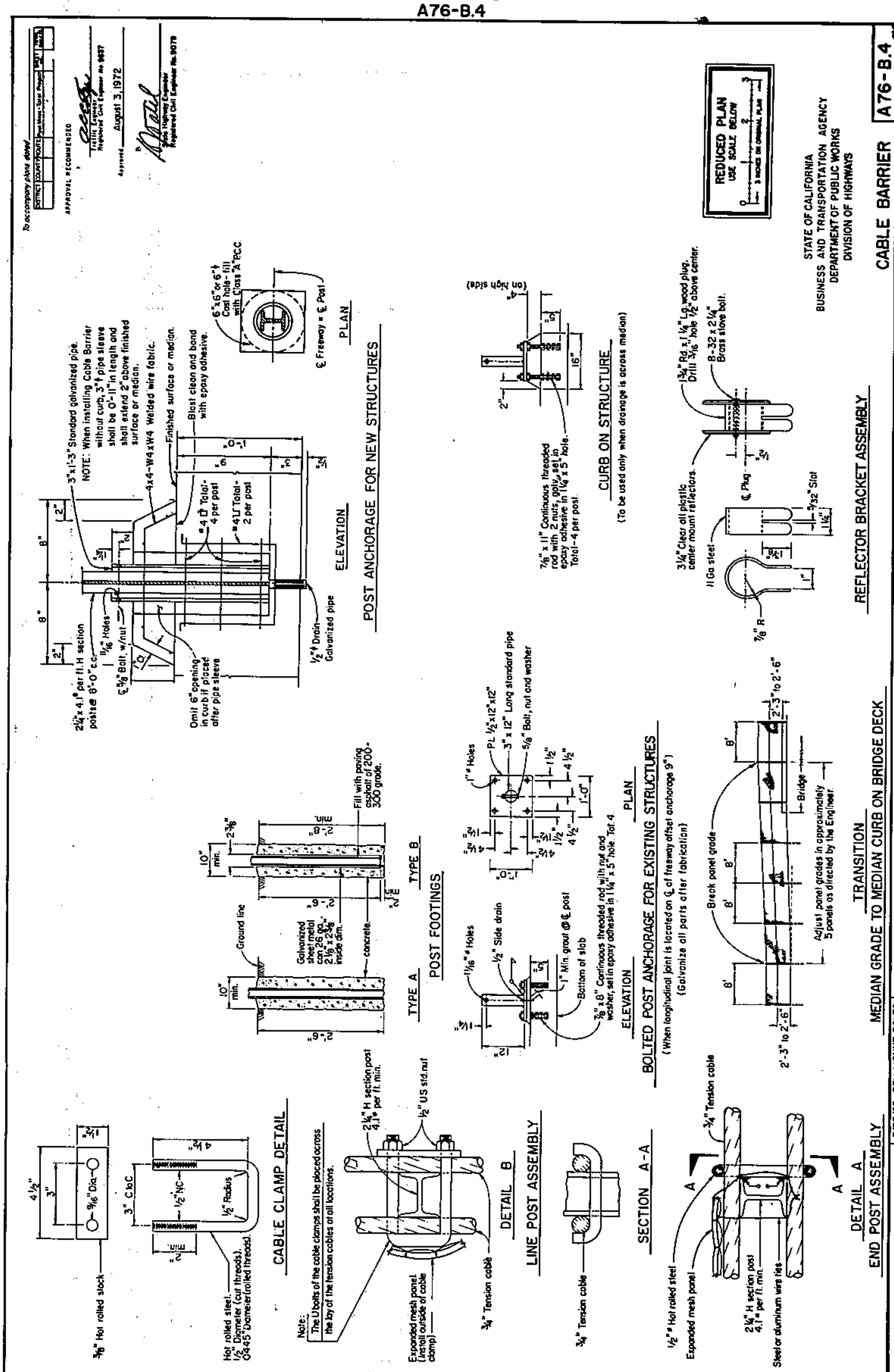

Figure 2

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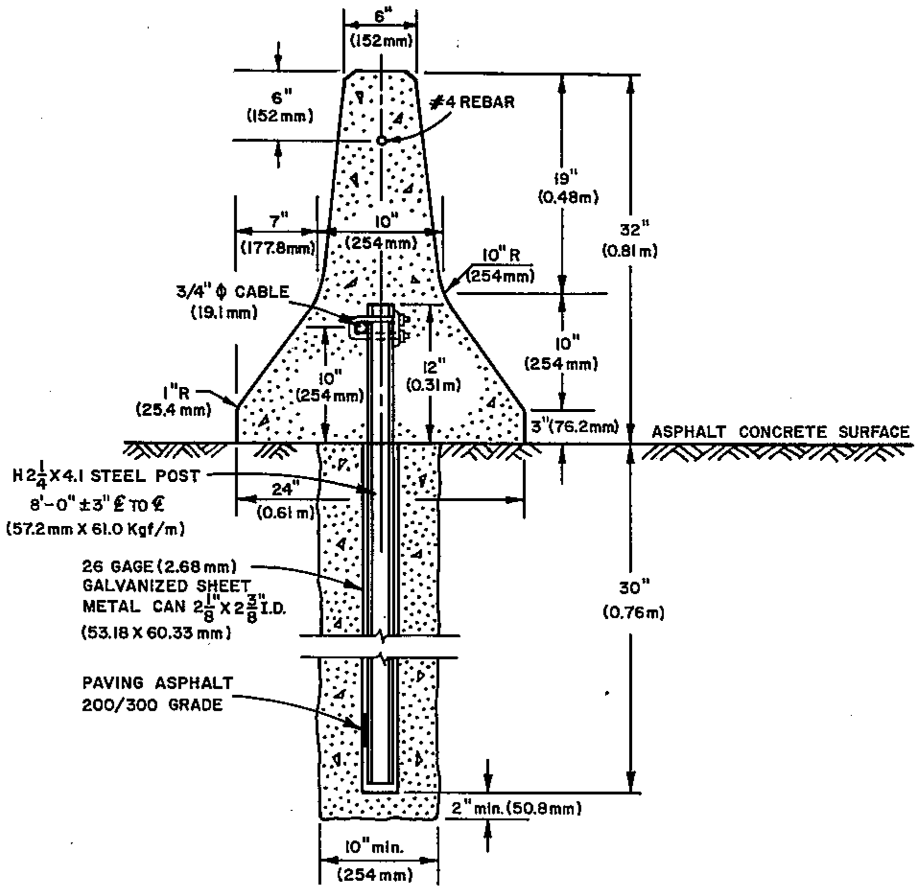

Fig. 3 TYPICAL SECTION OF SLIPFORMED CONCRETE BARRIER TYPE 50 OVER LOWERED CABLE BARRIER

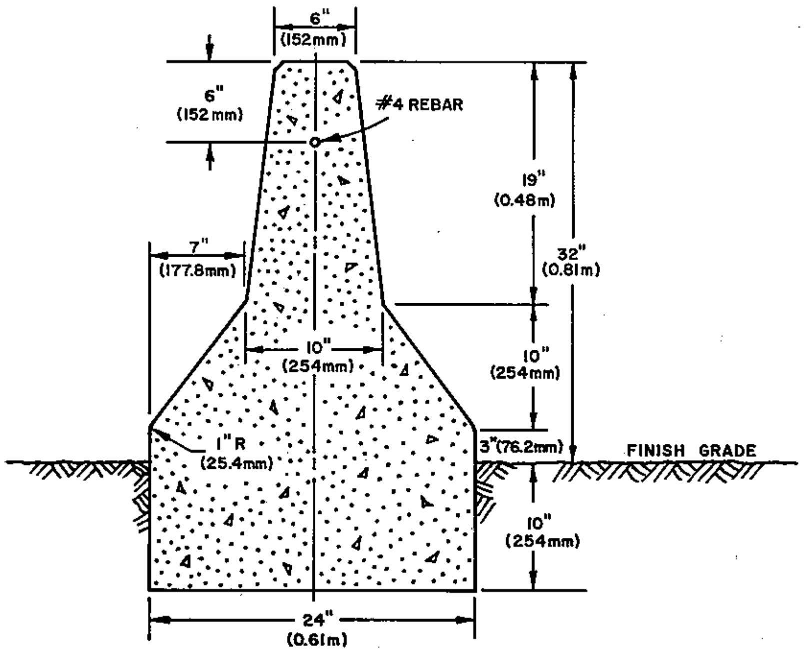

Fig. 4 TYPICAL SECTION OF CONCRETE BARRIER TYPE 50

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In addition to the above reasons it is realized that this method of construction will enable the contractor to construct the concrete barrier in a much shorter period of time, thereby reducing the potential of traffic hazards to the motoring public, and also to the contractor's workmen. Many of the barriers to be constructed by this method are in the metropolitan areas of California involving narrow medians where traffic volumes are quite high.

A vehicle weight of 4860 lbs (2204 kgf*), a nominal impact speed of 65 mph (105 km/hr), and a nominal 25° angle of impact were chosen for this test. These parameters are considered representative of the more severe conditions to which a highway barrier would be subjected by passenger vehicles on California highways. In addition, they are nominally the same as the impact parameters for our previous tests on Concrete Barrier Type 50.

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*kgf = kilogram-force; 1 kgf = 2.2 lbs.

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II. CONCLUSIONS AND IMPLEMENTATION

A. Conclusions

1. The modified Concrete Barrier Type 50 Slipformed Over Lowered Cable Barrier successfully contained and redirected a 4860 lb (2204 kgf) vehicle impacting at a severe angle of 27° and a high speed of 68 mph (109 km/hr).

2. The vehicle deceleration forces and damage were similar to those on comparable tests of the standard Concrete Barrier Type 50, already tested successfully in 1967[1].

3. The test barrier suffered no structural failures.

4. The only visible signs of barrier damage were tire scuff marks and a small spalled area at a construction joint adjacent to the impact area.

5. There was no significant transverse or longitudinal barrier movement or tilting during or as the result of impact.

B. Implementation

1. Based on the results of this test, the construction method used for this barrier is now permitted as an alternate method for constructing Concrete Barrier Type 50 on projects where cable barrier is being replaced by concrete barrier.

2. The State of California will obtain the following benefits resulting from the successful testing of this alternate barrier construction method:

   a. Approximately one million dollars in concrete median barrier construction costs can be saved based on the replacement of 200 miles (322 km) of cable barrier with concrete median barrier.

   b. Less construction time will be required. The cable barrier post footings will not have to be removed. The excavation and pouring of the 24" x 10" (610 x 254 mm) concrete footing for the original Concrete Barrier Type 50 design will be eliminated.

   c. The reduction in construction time will reduce the length of time the contractor's workmen and the State's inspectors are exposed to high speed traffic. It will also reduce the time interval when the flow of traffic is interrupted by traffic lane closures. Traffic lanes often times are closed to provide a safe work area while the concrete median barrier is being constructed. Both the reduction in construction time and lane closure time will result in improved safety for the contractor, the State, and the motorist.

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III. TECHNICAL DISCUSSION

A. Barrier Design and Construction

The 97'-0" (29.6m) concrete test barrier was built on an asphalt concrete surface, Figure 5. Figure 3 shows the typical section of the barrier. A complete barrier plan and a summary of essential specifications are presented in the Appendix.

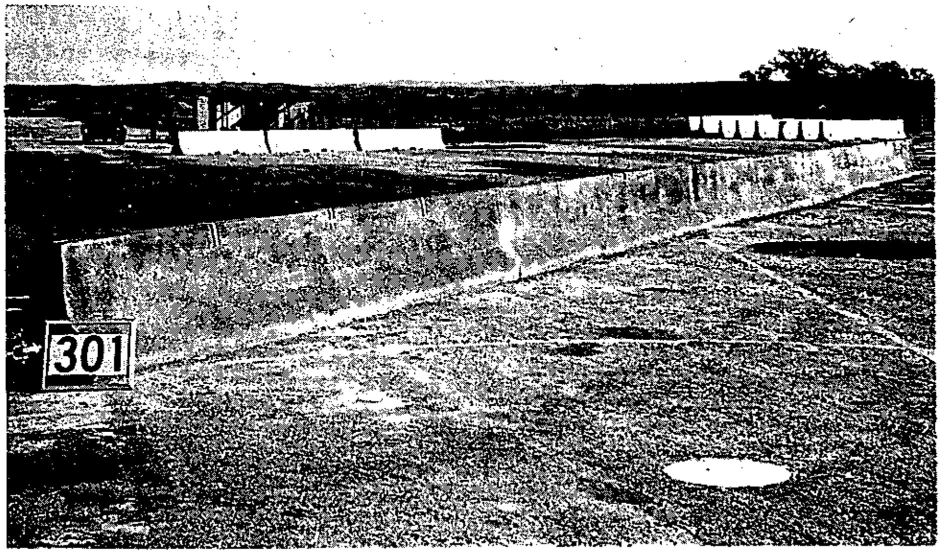

FIGURE 5, TEST INSTALLATION

Details for the cable barrier posts and footings, the end anchors, and the attachments for the test barrier were identical to those shown in the current Caltrans 1973 Standard Plan details for Cable Barrier, Figures 1 and 2, except for the following changes:

1. The H2-1/4 x 4.1 (57.2 mm x 6.10 kgf/m) steel posts projected only 1'-0" (0.305 m) above the paved surface.

2. Only one 3/4" (19.1 mm) diameter cable was attached with U-bolts to the posts at a height of 10" (254 mm) above the paved surface.

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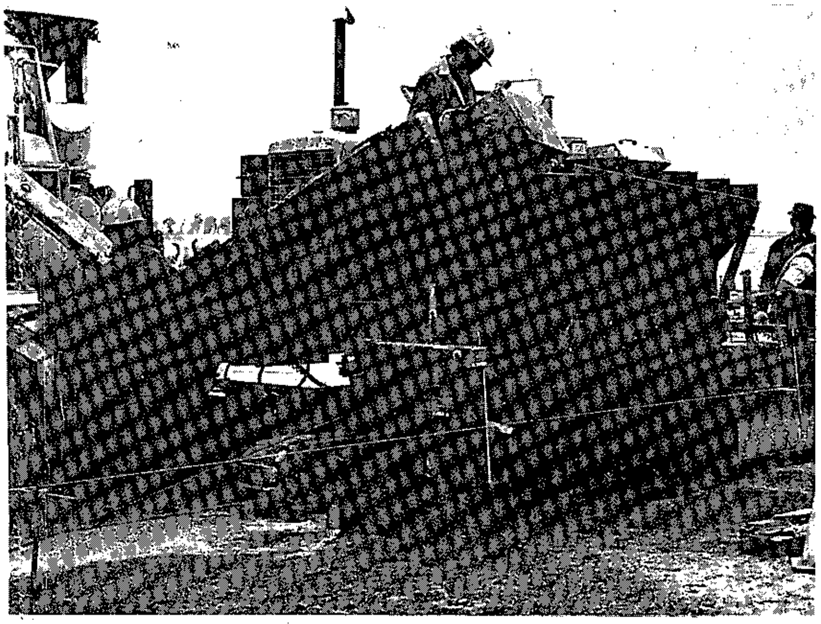
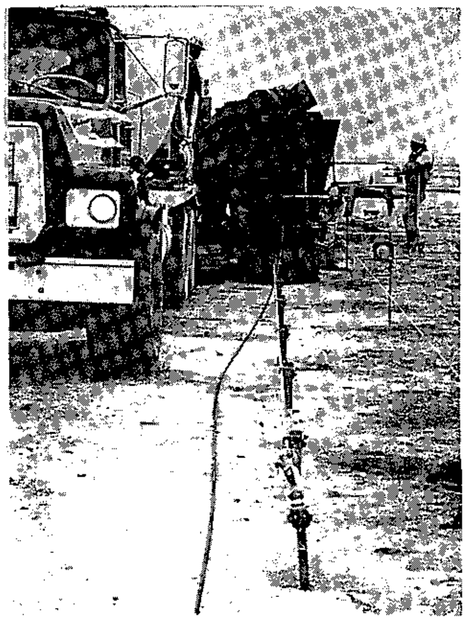
3. The concrete end anchors were placed 7'-6" (2.29 m) from the end posts instead of 6'-0" (1.83 m). This 6'-0" (1.83 m) dimension was added to a revised Standard Plan after the test installation was built.

4. Paving asphalt grade 120/150 was used instead of grade 200/300. It was felt that this change would not affect the performance of the barrier since the asphalt is used primarily so that maintenance men can easily replace damaged cable barrier posts.

The modified Concrete Barrier Type 50 was slipformed over the steel post stubs and attached cable by slipforming equipment manufactured by Miller Formless Co., Inc. of McHenry, Illinois. This particular machine was equipped with a wall mule, an on-board concrete supply, and a transfer auger. Modern Alloys, Inc. of Stanton, California (a subsidiary of Transportation Safety Systems, Inc.) was contracted to build the test installation. Figures 6 and 7 show the machine during the slipforming operation. The asphalt concrete surface was swept before the slipforming operation began.

FIGURES 6 AND 7, MILLER FORMLESS MACHINE DURING SLIPFORMING OPERATION

Contraction joints were placed in the concrete barrier every 20'-0" (6.1 m) along the length of the test installation. Figures 8 and 9 show the barrier before and during the finishing operation.

The 28 day average compressive strength of the concrete used for the slipformed barrier was 4610 psi (324 kgf/cm^2).

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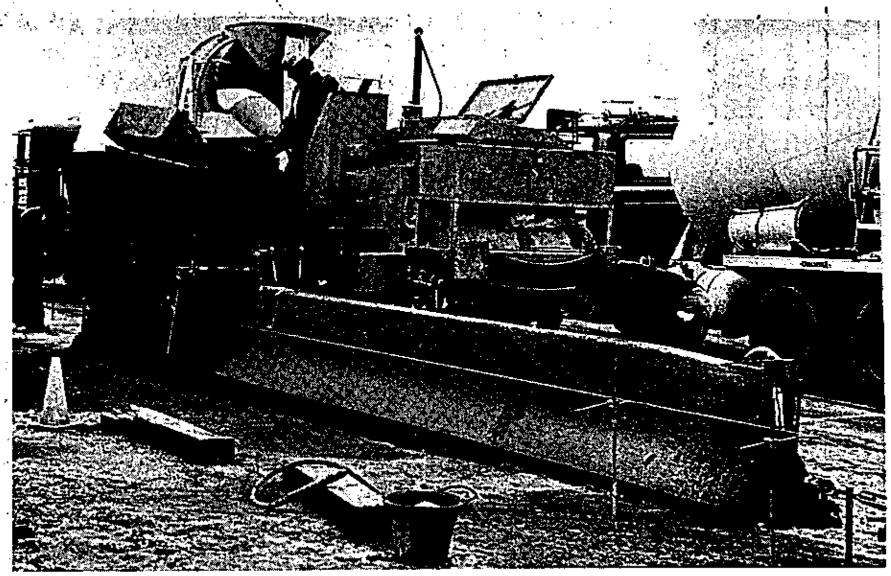

FIGURE 8, SLIPFORMED BARRIER BEFORE START OF FINISHING OPERATION

FIGURE 9, SLIPFORMED BARRIER DURING THE FINISHING OPERATION

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The soil in the vicinity of the site has a high supportive value. It consists of a layer of stiff, overconsolidated clay in the top 1.5 ft (0.46m) of soil and a layer of sandy clay with gravel and sand with gravel and hardpan, from 1.5 to 4.5 ft (0.46-1.37 m) of depth.

B. Test Equipment and Procedure

A 1969 Dodge Polara sedan was used for this test. The vehicle weight of 4860 lbs (2204 kgf) included the on-board instrumentation, a dummy, and a gas tank filled with water. The vehicle was self-propelled and directed into the impact area by a cable guidance system.

High speed and normal speed movie cameras and still cameras were used to record the impact event and the condition of the vehicle and the barrier before and after impact.

An anthropometric dummy with accelerometers mounted in its chest and head cavities was placed in the driver's seat to obtain motion and deceleration data. The dummy, Sierra Stan, Model P/N 292-850, manufactured by Sierra Engineering Company, is a 50th percentile male weighing 165 lbs (75 kgf). The dummy was restrained by a standard lap seat belt during the test.

Accelerometers were also mounted on the floorboard of the test vehicle. Deceleration data was collected to judge impact severity and to evaluate vehicle occupant injury tolerances.

Two Houston Deflection Potentiometers, mounted on the backside of the barrier, 6" (152 mm) down from the top and located 6 ft (1.83 m) on either side of the impact point, measured barrier deflection during impact.

The Appendix contains a detailed description of: the mechanical instrumentation in the test vehicle; photographic equipment and data collection techniques; electronic instrumentation and data reduction methods; and accelerometer records.

C. Test Results

The 4860 lb (2204 kgf) Dodge Polara impacted the test barrier at about 38'-6" (11.7m) from the upstream end and 1'-6" (0.46m) downstream from a contraction joint at a speed of 68 mph (109 km/hr) and an angle of 27°. The vehicle, redirected by the sloped face of the concrete barrier, exited at an angle of 7° and a speed of 50 mph (80 km/hr). During redirection, the vehicle remained in contact with the barrier for 13 ft (3.97m), rolled away from the barrier to a maximum roll angle of 26.5°, and attained a maximum airborne height of 3.2 ft (0.98 m). After traveling an airborne

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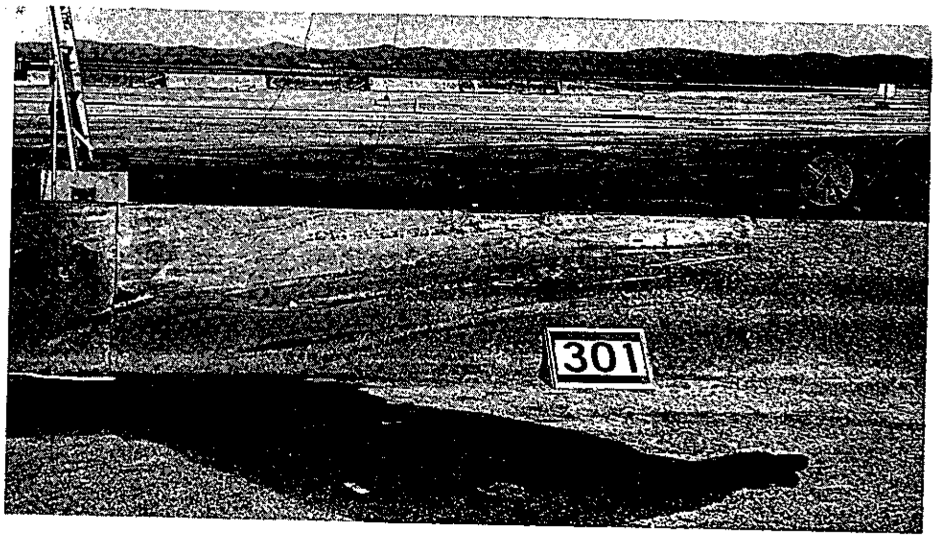
distance of about 30 ft (9.15 m), the vehicle returned to the pavement surface, rebounding to a maximum distance of approximately 24 ft. (7.3m) from the barrier, and arced along a trajectory path back toward the barrier. The vehicle came to rest, pointing back towards the barrier, approximately 154 ft (47.0m) from the end of the test barrier.

There was no evidence of any structural failure of the barrier. No visible cracks were detected. The only damage imparted to the barrier was a small spalled area 5" x 4" x 1/2" (127 x 102 x 13 mm) at a contraction joint near impact and a few scrapes and tire marks. Figures 10 and 11 show the barrier damage.

FIGURE 10, BARRIER DAMAGE



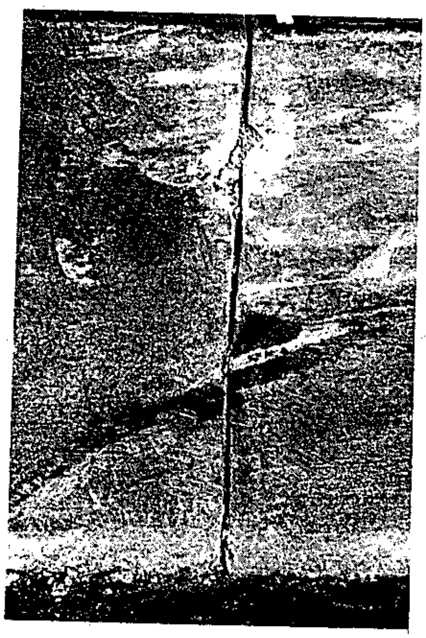


FIGURE 11, BARRIER DAMAGE AT CONTRACTION JOINT SHOWN IN FIGURE 10

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Principal damage to the test vehicle included:

1. The left front quarter was severely crushed.

2. The front bumper was pushed up into the engine compartment in the vicinity of the left front wheel well.

3. The left front door was jammed and buckled outward approximately 4 1/2" (114 mm) from its original plane.

4. The left front wheel A-frame and stabilizer bars were bent under the vehicle.

5. The left front tire was flat.

6. The left side of the radiator was pushed back to the fan.

7. The hood was sprung open.

8. The front windshield was shattered due to frame distortion and glass fragments were found inside the passenger compartment.

9. The dashboard fractured near the steering wheel column.

10. There was minor sheet metal buckling at the roof above the left door post.

The test vehicle could not be driven away. The Traffic Accident Scale (TAD) [2] symbols are: FL-6, LFQ-6, and LBQ-1. The Vehicle Damage Index (VDI) [3] classification is 11FYEW7. Figures 12 and 13 show the vehicle damage.

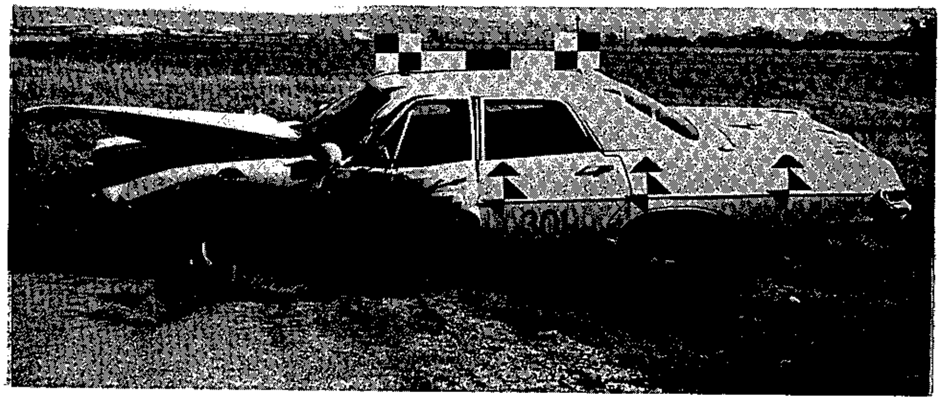

FIGURE 12, VEHICLE DAMAGE

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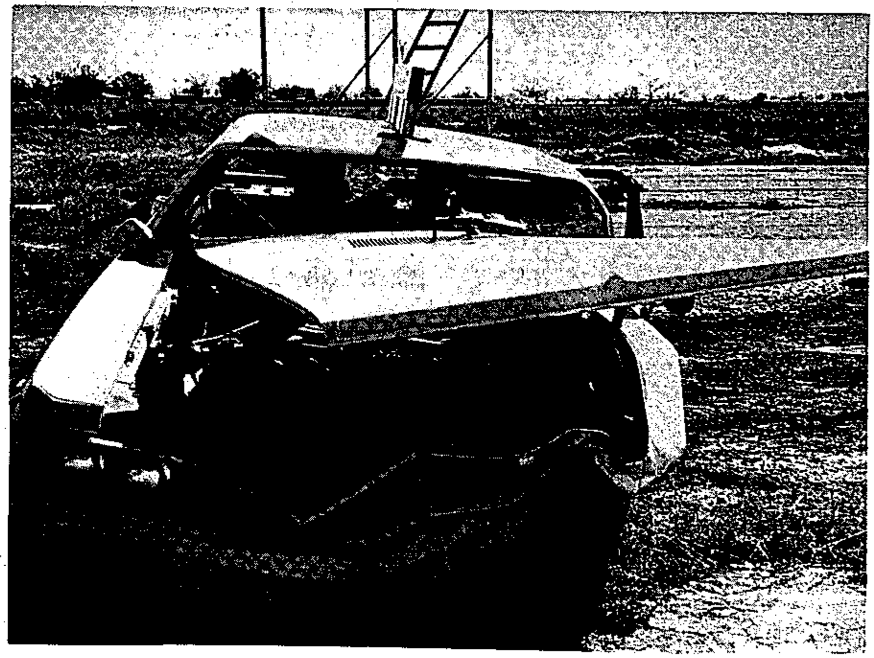

FIGURE 13, VEHICLE DAMAGE

Upon impact, the dummy, restrained by a standard lap belt, was thrown forward into the left front door of the vehicle hitting its head on the window frame. The dummy sustained cuts on its left hand and on its face. Small glass fragments were embedded in its facial cuts. The section on Impact Severity under Discussion of Results evaluates the passenger hazard.

Figure 14 summarizes the results of the test. The exit angle represents the direction the center of gravity of the vehicle was moving immediately following final contact with the barrier. This angle is estimated using high speed movies from cameras mounted over the impact area. It is not necessarily the heading of the longitudinal axis of the vehicle.

The exit speed is also estimated using high speed movies. The camera used for this estimate was mounted on a tripod and aimed perpendicular to the barrier.

The value of maximum vehicle rise represents the maximum height above ground of the left front wheel of the vehicle.

The maximum 50 millisecond average vehicular deceleration values are the average results of either two lateral or two longitudinal accelerometers.

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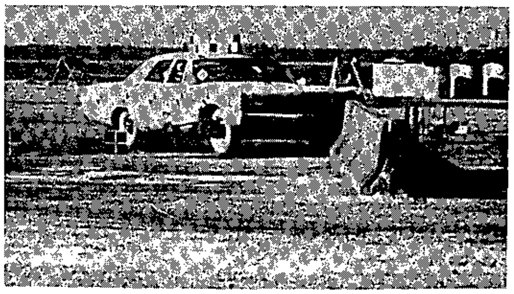

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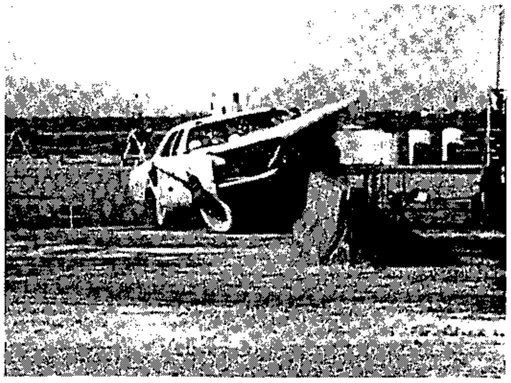

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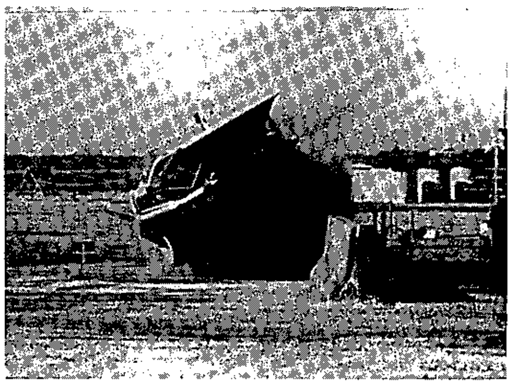

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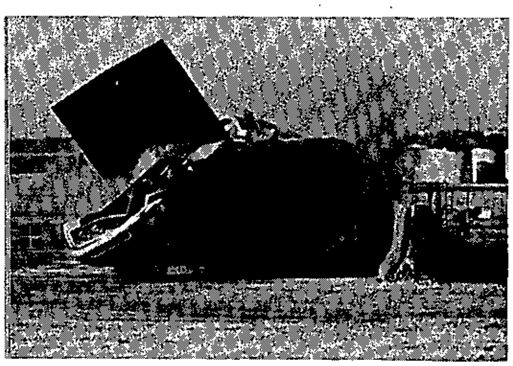

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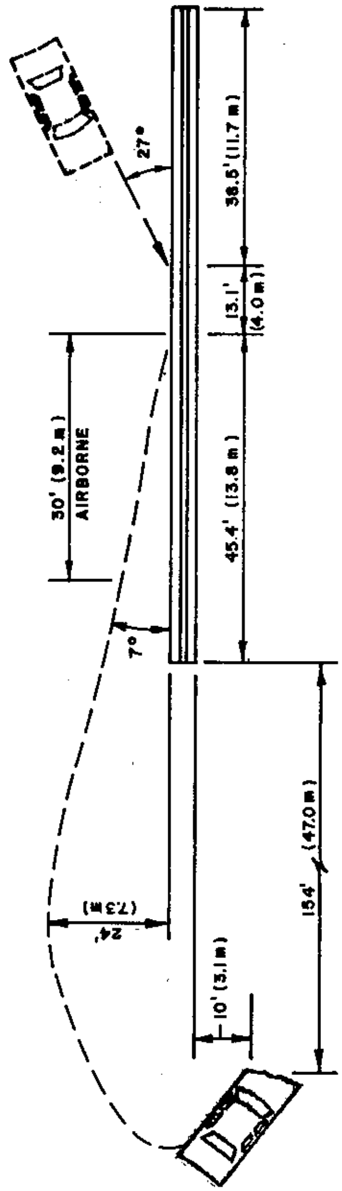

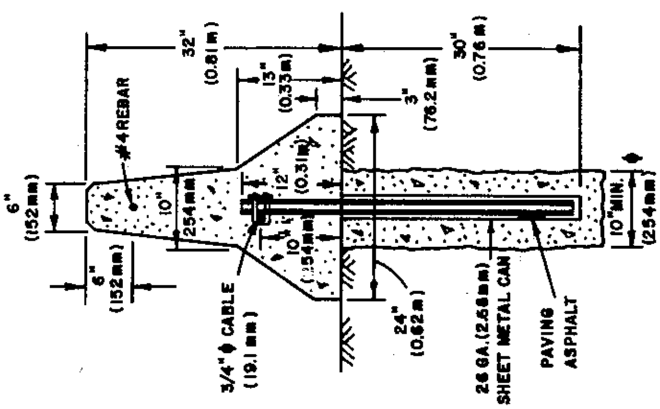

BARRIER .... Slipformed Type 50 Over Lowered Cable Barrier
POST .... H 2 1/4 x 4.1 Steel (57.2 mm x 6.10 Kgf/m)
POST SPACING .... 8'-0" (2.44 m)
LENGTH OF INSTALLATION .... 97'-0" (29.6 m)
MAX. PERM. BARRIER DEFL. (lateral) . 0.075" (1.91 mm)
MAX. 50msec. AVG. VEHICULAR DECELERATION –
lateral .... 13.8 G's (136 m/s^2)
longitudinal .... 11.7 G's (115 m/s^2)
DUMMY RESTRAINT .... Lap Belt

TEST NO 301
DATE 1/22/74
VEHICLE .... 1969 Dodge Polara
VEHICLE WEIGHT .... 4860 lbs. (2204 kgf) (w/dummy & instrumentation)
IMPACT SPEED .... 68 mph (109 km/hr)
IMPACT ANGLE .... 27°
EXIT ANGLE .... 7°
EXIT SPEED .... 50 mph (80 km/hr)
MAX. VEHICLE RISE .... 3.2' (0.98 m)

Figure 14 . TEST 301

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D. Discussion of Results

The performance of this longitudinal barrier was evaluated primarily with regard to the appraisal factors outlined in Reference 4. Table 1 summarizes the test parameters and results of other full scale crash tests on barriers with the same configuration tested under similar impact conditions.

1. Structural Integrity

The modified Concrete Barrier Type 50 Slipformed over Lowered Cable Barrier is equivalent in structural strength to Concrete Barrier Type 50 and to other barriers tested with the same profile. The test barrier successfully redirected a 4860 lb (2204 kgf) vehicle impacting at a speed of 68 mph (109 km/hr) and an angle of 27°. There was no significant tilting or lateral barrier movement. The maximum permanent lateral barrier deflection was 0.075" (1.91 mm), measured at a point 6" (152mm) down from the top of the barrier.

The test barrier did not fail structurally. There were no visible cracks in the barrier. Other than tire marks, minor sheet metal scrapes, and one small spalled area at a contraction joint adjacent to impact, all of which would require minor maintenance repair, the test barrier suffered negligible damage. No barrier debris intruded into the passenger compartment of the vehicle during the test.

2. Impact Severity

This proof test was conducted to verify the structural stength and stability of the barrier. Under these severe impact conditions, [4860 lb (2204 kgf), 68 mph (109 km/hr), 27°], the value of 11.7 g's for the longitudinal vehicle deceleration is relatively high as compared to the results of previous tests on this same barrier profile, Table 1.

However, the kinetic energy for this test, Test 301, was 13% greater than for Test 264 and 30% greater than for Test 262. Also, a different make vehicle was used for Test 262 than for Test 264 and 301. Both vehicle kinetic energy and vehicle structural strength and stiffness affect vehicle decelerations. Values of vehicle decelerations for the Texas concrete median barriers, CMB-1 and CMB-2, can not be compared with the results of other tests listed in Table 1 because a different method of calculating vehicle decelerations was used.

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TABLE 1

TEST NO.	REF.	BARRIER (1)	LENGTH ft(m)	FOOTING, ANCHORAGE	VEHICLE TEST PARAMETERS: YEAR & MAKE	WEIGHT lbs(kgf)	SPEED mph (km/hr)	IMPACT ANGLE°	KINETIC ENERGY 1000ft-lb(m-kgf)	VEHICLE (2) DECELERATION G's: LONG.	LAT.	VEHICLE TRAJECTORY: EXIT(4) ANGLE°	RISE(5) ft(m)	ROLL(6) degrees	EXIT Speed mph (km/hr)	BARRIER CONTACT ft(m)	MAX(7) REBOUND ft(m)	REMARKS
162	1	Unreinforced Concrete	160 (48.8)	24"x 10" (0.61 x 0.25 m) Concrete Footing	1965 Dodge Polara	4540 (2059)	63 (101)	25	602.2 (83.3)	NA	NA	16	NA	25	51 (82)	12.5 (3.8)	47 (14.3)	Vehicle redirected
262	5	Prestressed Type 50 4-1/2" ϕ Strands @ 28 kips each	150 (45.8)	NONE	1970 Mercury Monterey	4960 (2249)	59 (95)	25	577.0 (79.8)	7.0	11.6	NA	2.8 (0.85)	25	57 (92)	13 (4.0)	43 (13.1)	Vehicle redirected, but rolled
263	5	Prestressed Type 50 4-1/2" ϕ Strands @ 28 kips each	150 (45.8)	NONE	1970 Mercury Monterey	4960 (2249)	66 (106)	25	722.0 (99.9)	NA	NA	8	2.7 (0.82)	35	55 (88)	14 (4.3)	51 (15.6)	Vehicle redirected, but rolled; torsional fracture in barrier.
264	5	Prestressed Type 50 3 of 4-1/2" ϕ Strands @ 28 kips each; 1 @ 0 kips	150 (45.8)	NONE	1969 Dodge Polara	4860 (2204)	64 (103)	25	665.2 (92.0)	5.2	13.0	5	3.0 (0.92)	28	54 (87)	15 (4.6)	52 (15.9)	Vehicle redirected
265	5	Prestressed Type 50 4-1/2" ϕ Strands @ 10 kips each	150 (45.8)	NONE	1968 Dodge Polara	4780 (2168)	62 (100)	24	614.0 (84.9)	NA	NA	4	3.7 (1.13)	40	52 (84)	13 (4.0)	42 (12.8)	Vehicle redirected; hairline fracture
CMB-1	6	Reinforced Concrete 8 - #5 rebars continuous	50 (15.3)	3-18" (0.46 m) diameter CIDH Concrete Shafts	1963 Plymouth	4000 (1814)	62.4 (100)	25	520.5 (72.0)	(3) 8.7/3.2	(3) 16.1/4.4	7.3	NA	NA	NA	NA	NA	Vehicle redirected
CMB-2	6	Reinforced Concrete 8 - #5 rebars continuous	150 (45.8)	1" (25.4 mm) layer of hot mix asphalt at front & back base of barrier	1964 Chevrolet	4230 (1918)	55.7 (90)	25	438.6 (60.7)	(3) 10.3/1.8	(3) 13.3/2.8	6	NA	NA	NA	NA	NA	Vehicle redirected
301		Slipformed Type 50 Over Lowered Cable	97 (29.6)	H2$\frac{1}{4}$x4.1 (57.15mm x 6.10 Kgf/m) Steel Posts @ 8'-0" (2.44 m) spacing 1'-0" (0.31 m) above grade; $\frac{3}{4}$" (19.1 mm) cable attached to posts; turnbuckle W/anchor rod embedded in conc. end anchors	1969 Dodge Polara	4860 (2204)	68 (109)	27	751.0 (103.9)	11.7	13.8	7	3.2 (0.98)	27	50 (80)	13.1 (4.0)	31 (9.5)	Vehicle redirected

(1) All have the New Jersey median barrier cross section except CMB-1 and CMB-2 which are 2" (25.4 mm) wider at the top and 3" (76.2 mm) wider at the bottom.

(2) 50 millisecond averages except for CMB-1 & 2.

(3) Maximum/average

(4) Direction the c.g. of the vehicle was moving immediately following final contact with the barrier.

(5) Max. height above ground of the left front wheel.

(6) Max. airborne rotation about the longitudinal axis of the vehicle away from the face of the barrier immediately following redirection.

(7) Max. distance (including the width of the vehicle) that the vehicle arched away from the face of the barrier.

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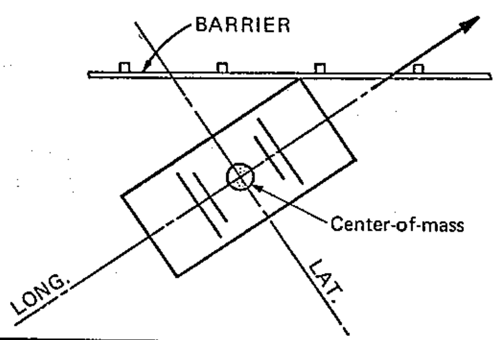
Both the lateral and longitudinal values of vehicle deceleration, 13.8 g's and 11.7 g's, for this test exceeded the guideline values of maximum vehicle decelerations for occupants restrained by lap belts, Table 2[7,8], but not the values for occupants restrained by lap and shoulder belts. However, these limits were based primarily on longitudinal deceleration data since little was known at that time about the effect of combining both lateral and longitudinal components of deceleration[9]. Table 4 in Reference 4 showing acceptable deceleration levels was not used because it applied to impacts of 15° or less.

Barrier Performance Rating†	Maximum Vehicle Decelerations (g's)*			
	Lateral	Longitudinal	Total	Remarks
A	3	5	6	Preferred Range
B	5	10	12	
C	15	25	25	



*Vehicle rigid body decelerations; maximum 500 g/sec onset rate; highest 50 msec average.
†A - limits for unrestrained passenger.
B - limits for passenger restrained by lap belt.
C - limits for passenger restrained by lap and shoulder belts.

TABLE 2

Table 3 presents a summary of deceleration data for barriers tested with the same profile and under similar impact conditions.

The Gadd Severity Index, Table 3, was obtained by integrating the resultant of the head deceleration raised to the 2.5 power over a 50 millisecond time interval. The value of 927 for this test is close to the threshold value of 1000 above which serious injury or death might be expected due to concussion. The severity index is

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TABLE 3 - SUMMARY OF DECELERATION DATA

CALIF. TEST NO.	TEST CONDITIONS			DECELERATIONS G's (1)				GADD SEVERITY INDEX (3)	MAX. LAP BELT LOAD lbs (kgf)
				VEHICLE		ANTHROPOMETRIC DUMMY			
	IMPACT ANGLE, deg.	IMPACT SPEED mph (km/hr)	KINETIC ENERGY K-ft (kgf-m)	LAT.	LONG.	CHEST LONG.	HEAD RESULT. (2)		
262	25	59 (95)	577.0 (79.8)	11.6	7.0	8.6	26.7	234	1350 (612)
264	25	64 (103)	665.2 (92.0)	13.0	5.2	5.6	30.1	447	400 (181)
301	27	68 (109)	751.0 (103.9)	13.8	11.7	11.8	37.7	927	263 (119)

1. Maximum 50 m sec. average.
2. Vector resultant of longitudinal, lateral, and vertical accelerometer traces.
3. Maximum 50 m sec. interval.

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only a conservative approximation and therefore is subject to many variables. Some of these variables are[10]: (1) sophistication of the dummy; (2) interpretation limited to evaluation of blows to the forehead; (3) difficulty in determining the exact area of contact; (4) variables such as portions of vehicle struck, original dummy position, seat position, seat belt tautness, etc. have an affect on dummy motions, (5) time interval used for calculations.

3. Vehicle Trajectory

All the vehicle trajectory parameters for this test compared as well or better than the results of previous tests on this type of barrier. Table 1 summarizes the following parameters; exit angle; maximum vehicle rise; roll; exit speed; distance in contact with barrier; and maximum rebound from the face of the barrier.

The value of maximum rebound was less in this test as compared with the results of previous tests. Differences might be attributed to: (1) how severely the vehicles were damaged during impact and (2) the instant the remote braking system on the vehicle was fired.

It is difficult to determine whether the post trajectory behavior of the test vehicle would pose a hazard to traffic traveling along the highway near the impact location. Other variables such as median width, median surface material and texture, weather conditions, sight distance, reaction time, etc. would also have to be considered along with post trajectory rebound in order to assess the possibility of multiple vehicle collisions. Figure 15 shows the final position of the test vehicle in relation to the test barrier.

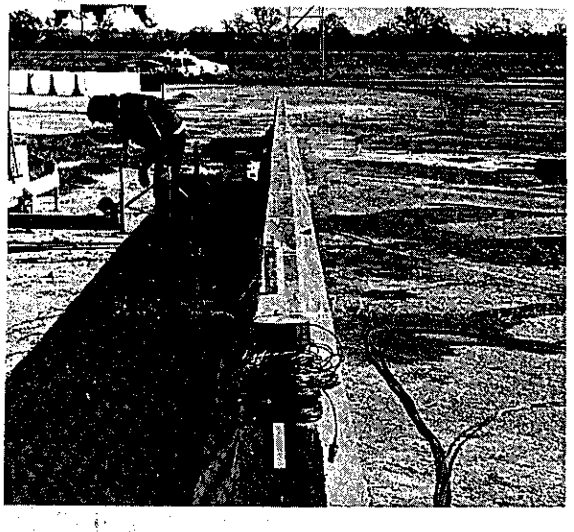

FIGURE 15, FINAL VEHICLE POSITION

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V. APPENDIX

A. Test Vehicle Equipment

Following is a description of the modifications made to the test vehicle prior to the impact test and the method of guiding the vehicle into the barrier.

1. The test vehicle gas tank was disconnected from the fuel supply line, drained and refilled with water. A one gallon safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

2. A solenoid-valve actuated CO_2 system was connected to the brake line for remote braking. With 700 psi (49.2 kgf/cm_2) in the accumulator tank, the brakes could be locked in less than 100 milliseconds after activation. The brakes were actuated by flipping a toggle switch at the remote control console.

3. The ignition system was connected to the brake relay in a failsafe interlock system. When the brake system was activated, the vehicle ignition was switched off.

4. The accelerator pedal was linked to a small electric motor which, when activated, opened the throttle. The motor was activated by a manually thrown switch mounted adjacent to the trunk on the rear of the test vehicle.

5. A micro switch was mounted below the front bumper and connected to the ignition system. A trip line installed 18 feet (5.5 m) from impact triggered the switch; thus opening the ignition circuit and cutting the vehicle motor prior to impact.

6. The left front and left rear tire sidewalls were painted different colors to delineate wheel contact and climb on the parapet face.

A cable guidance system was used to direct the vehicle into the barrier. The guidance cable, anchored at each end of the vehicle path, passed through a slipbase guide bracket attached to the left front wheel spindle of the vehicle. A steel angle post driven into the ground near the barrier projected high enough to knock the bracket off the vehicle just prior to impact so that the vehicle was free of the cable. Figure 1A shows the guidance bracket attached to the vehicle.

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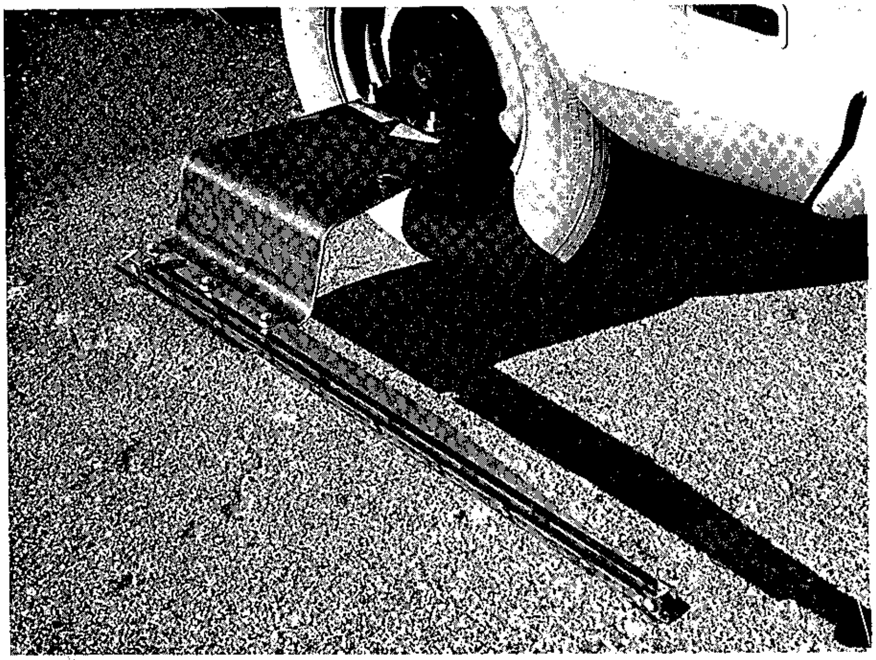

FIGURE 1A, CABLE GUIDANCE BRACKET

B. Photo-Instrumentation

Data film was obtained by high speed cinematography through the use of seven Photosonic 16mm cameras (250-400 frames per second). These cameras were located on tripods to the front, rear, and sides of impact and on a tower 35 ft (10.7m) above impact. All cameras were electrically actuated from a central control console Figure 2A. An eighth Photosonic camera was located in the test vehicle to record the motions of the anthropometric dummy. This camera was triggered by a tether-line actuated switch mounted on the rear bumper of the test vehicle.

All cameras were equipped with timing light generators which exposed reddish timing pips on the film at a rate of 1000 per second. The pips were used to determine camera frame rates and to establish time-sequence relationships. Additional coverage of the impacts was obtained by a 70mm Hulcher camera operating at a rate of 20 frames per second, and a 35mm sequence camera operating at 20 frames per second. Documentary coverage of the tests consisted of normal speed movies and still photographs taken before, during, and after impact. Data from the high-speed movies was reduced on a Vanguard Motion Analyzer. Procedures taken to instrument the crash vehicle and the test site to assist in the reduction of data are listed as follows:

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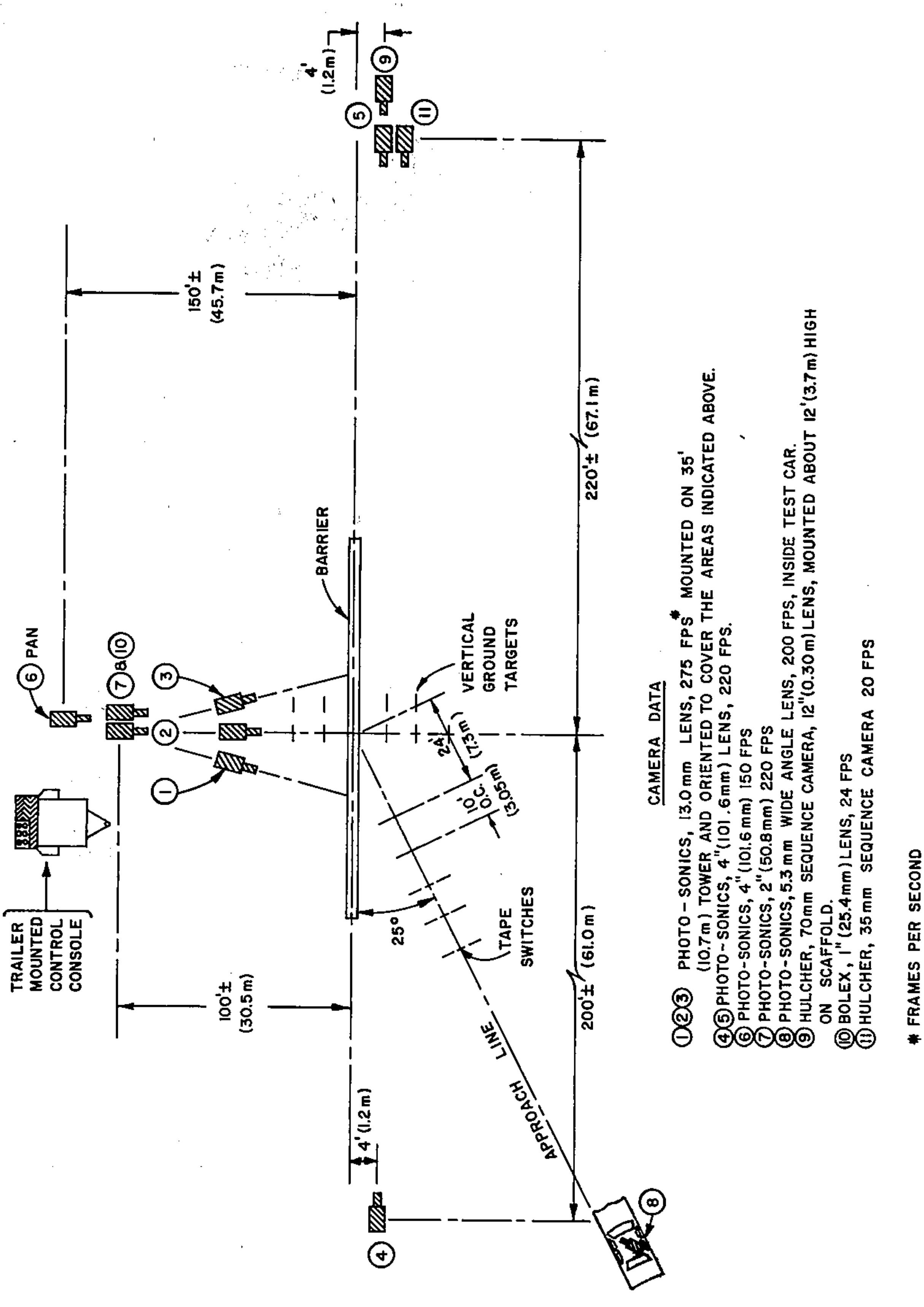

Figure 2A, CAMERA LAYOUT

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1. Targets were attached to the vehicle body and the face of the barrier, and placed at ground locations to the front and rear of the barrier.

2. Flashbulbs, mounted on the test vehicle, were electronically flashed to establish (a) initial vehicle/barrier contact and (b) the application of the vehicle's brakes.

3. Five tape switches were laid on the ground perpendicular to the vehicle path leading into the point of impact. Placed at 10-foot (3.05 m) intervals, the switches were actuated sequentially by the tires of the test vehicle, thus triggering a series of flashbulbs. The flashbulbs were in the field of view of all the data cameras and were used to correlate cameras to collision events and to determine the impact velocity.

C. Electronic Instrumentation and Data

A total of eight Statham accelerometers, of the unbonded strain gage type, were used for deceleration measurement. Of these, four were mounted, one in the chest and three in the head cavity, in the anthropometric dummy, and four were mounted on the floor-board of the test vehicle. In addition one seat belt transducer was installed on the dummy's lap belt. The nine transducers transmitted data through a 1000 ft. (305m) Belden #8776 umbilical cable that ran from a rear mounting on the test vehicle to a 14 channel Hewlett Packard 3924C magnetic tape recording system. This recording system was mounted in an instrumentation trailer located in the test control area. Figure 3A shows the location of the transducers in the test vehicle. Three pressure activated tape switches were mounted on the pavement at fixed intervals in the vehicle approach path. When activated by the test vehicle's tires, these switches produced sequential impulses which were recorded with the transducer signals on the tape recorder. Concurrently a 100 millisecond time cycle signal was impressed on the tape. All of the tape recorder data were subsequently played back through a Visicorder which produced an oscillographic trace (line) on paper. Each paper record contained a curve of data from one of the nine transducers, the signals from the three tape switches, and the 100 millisecond time cycle marking. Some of the records of accelerometer data had high frequency spikes which made analysis difficult. Therefore, the original test data was filtered at 100 Hertz with a Krohn-Hite filter. The smoother resultant curves gave a good representation of the overall vehicle deceleration without significantly altering the amplitude and time values of the deceleration pulse. Transducer records are presented in Figures 4A and 5A.

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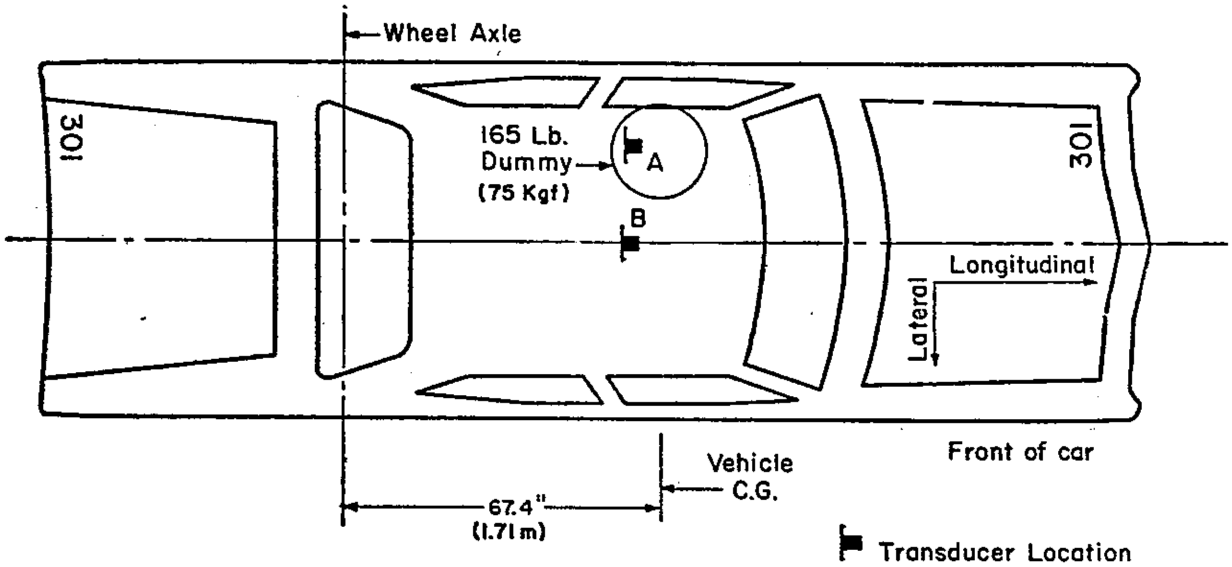

DATA CHANNEL NO.		LOCATIONS
1.	A Longitudinal -	Accelerometer in dummy's head.
2.	A Vertical - - -	Accelerometer in dummy's head.
3.	A Lateral - - -	Accelerometer in dummy's head.
4.	A Longitudinal -	Accelerometer in dummy's chest.
5.	B Lateral - - -	Accelerometer mounted on vehicle floor at C.G.
6.	B Longitudinal -	Accelerometer mounted on vehicle floor at C.G.
7.	B Longitudinal -	Accelerometer mounted on vehicle floor at C.G.
8.	B Lateral - - -	Accelerometer mounted on vehicle floor at C.G.
9.	A	Seat belt transducer across dummy's lap.

NOTE: Location A (for accelerometers) is on the back of the head or in the chest cavity of the dummy; Location B is on a steel angle bracket welded to the floor at the vehicle center of gravity.

FIGURE 3A- VEHICLE INSTRUMENTATION

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Figure 4A VEHICLE DECELERATION VS TIME
TEST 301, 68 MPH, 27 DEGREES
DATA FILTERED AT 100 HERTZ
SLIPFORMED TYPE 50 OVER LOWERED CABLE BARRIER

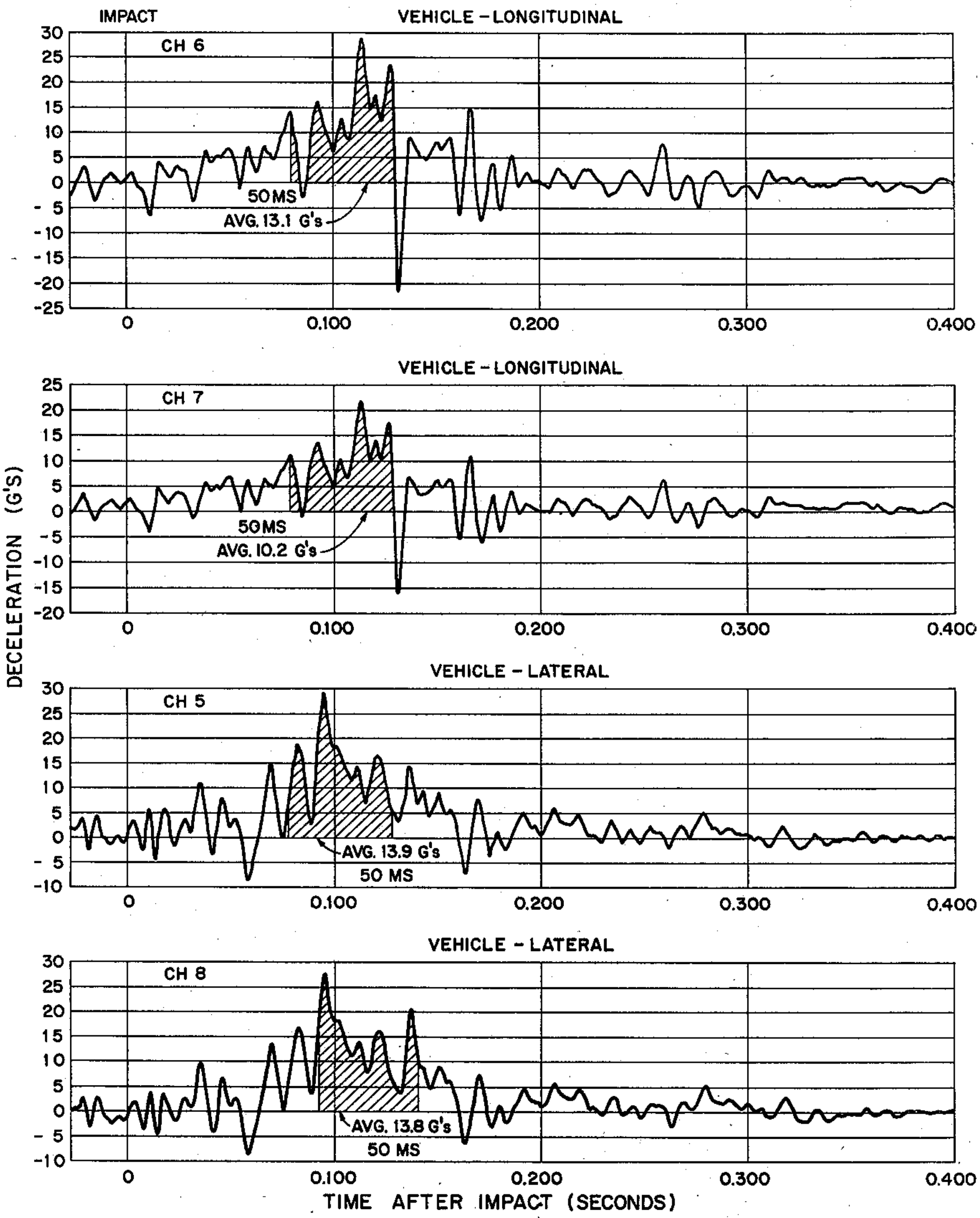

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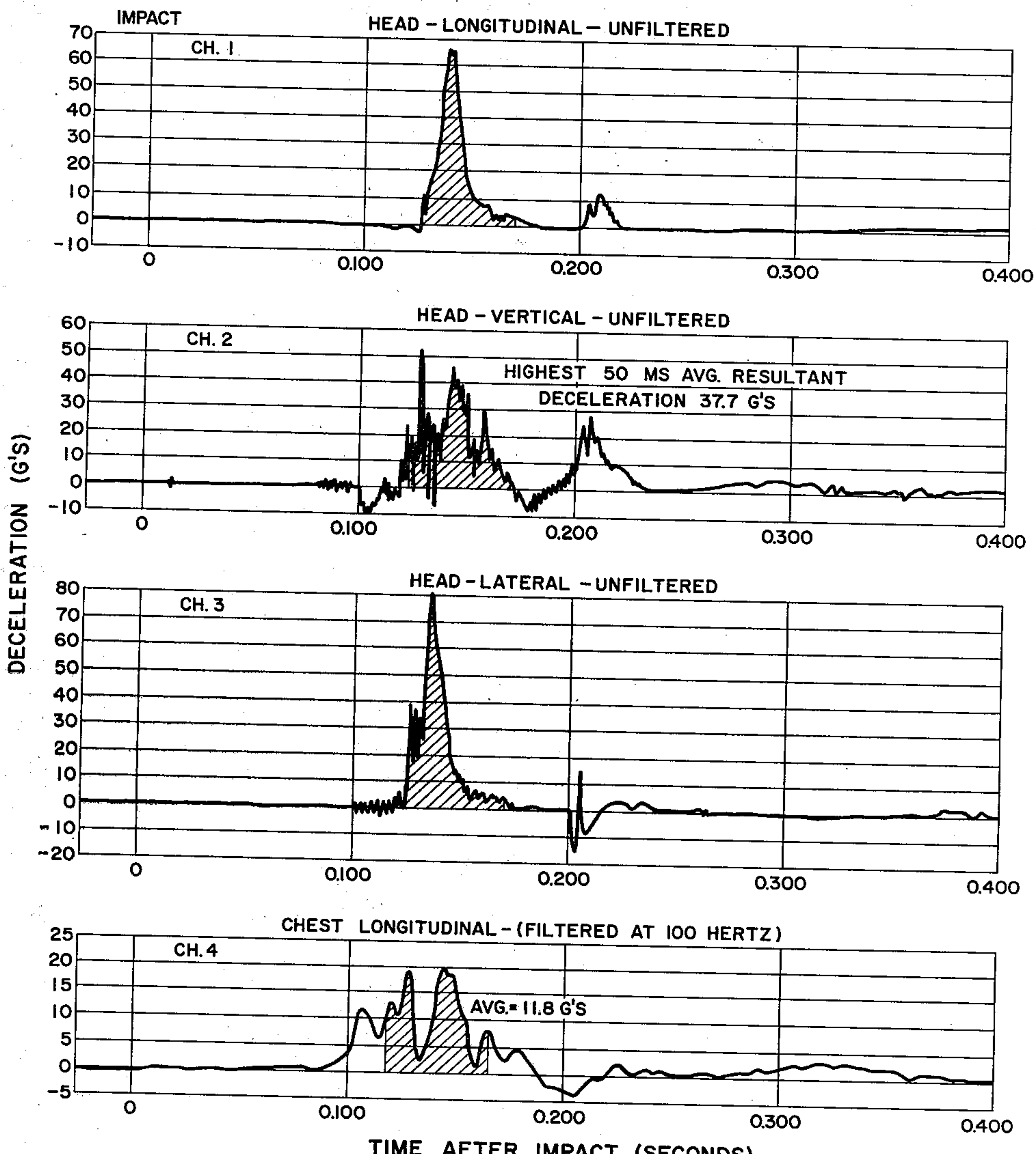
Figure 5A DUMMY DECELERATION VS TIME
TEST 301, 68 MPH, 27 DEGREES, LAP BELT
SLIPFORMED TYPE 50 OVER LOWERED CABLE BARRIER



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Houston Deflection Potentiometers, Figure 6A measured the dynamic deflection of the test barrier during impact. Figure 7A shows the record of this measurement.

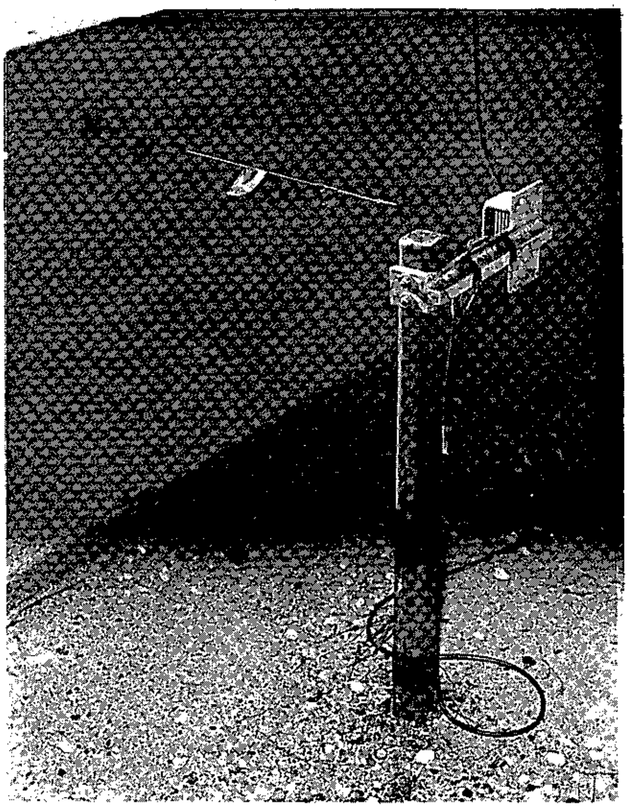

FIGURE 6A, HOUSTON DEFLECTION POTENTIOMETER

D. Summary of Specifications and Barrier Plan

Following is a list of the essential specifications and the detailed drawing used for the test barrier.

1. Concrete for the post footings shall be Class B, a minimum of 470 lbs (213 kgf) of portland cement per cubic yard. Concrete for the Type 50 barrier shall be Class A, a minimum of 564 lbs (256 kgf) of portland cement per cubic yard. Type II modified portland cement shall be used.

2. The combined aggregate grading used for the concrete in the slipformed barrier shall be either the 1 1/2" (38.1 mm) maximum grading or the 1" (25.4 mm) maximum grading at the option of the contractor, or, when necessary to produce concrete that conforms to the requirements of these special provisions, the combined aggregates shall conform to the following provisions: If a 3/4" (19.1 mm) maximum grading

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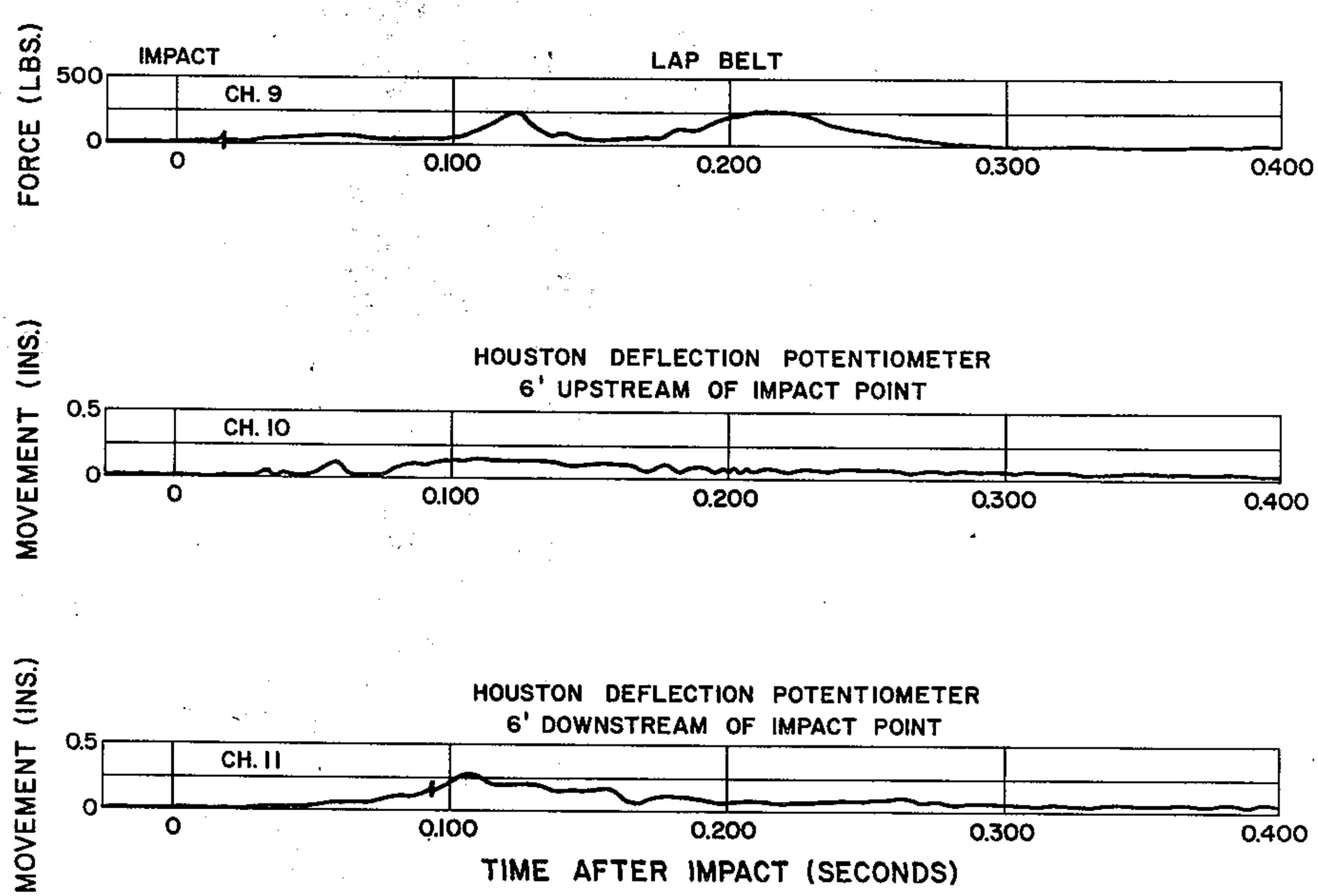
Figure 7A DUMMY LAP BELT LOAD VS TIME & BARRIER DEFLECTION

TEST 301, 68 MPH, 27 DEGREES

SLIPFORMED TYPE 50 OVER LOWERED CABLE BARRIER

DATA UNFILTERED



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is used, the concrete shall contain a minimum of 470 lbs (213 kgf) of cement per cubic yard; If a 3/8" (9.5 mm) maximum grading is used, the concrete shall contain a minimum of 564 lbs (256 kgf) of cement per cubic yard. An air-entraining agent shall be added during mixing in an amount to produce from 5 to 8 percent air by volume in the mixed concrete.

3. The reinforcing steel shall comply with ASTM A615 Grade 60.

4. The cable to be used shall be 3/4" (19.1 mm) preformed, 6 x 19, wire strand core or independent wire rope core (IWRC), galvanized ASTM Designation: 603, Class A coating, right regular lay, manufactured of improved plow steel with a minimum breaking strength of 46,000 lbs (20,862 kgf).

5. The posts shall be structural steel conforming to the specifications of ASTM Designation: A36; and shall be galvanized after fabrication. The steel for the U-bolts and plates shall conform to the requirements of American Iron and Steel Institute Designation: C1020, hot-rolled steel, with a minimum tensile strength of 55,000 psi (3866 kgf/cm^2). Nuts shall conform to the specifications of ASTM Designation: A307, for Grade B bolts.

6. Curing compound shall be chlorinated rubber curing compound.

7. Contraction joints shall be provided at 20 foot (6.1 m) intervals and may be formed with wastable or removable material as shown on the attached plan or by sawing. If contraction joints are formed by sawing, the work shall be accomplished within 24 hours after the barrier is placed. The exact time to be determined by the Engineer. If the joints are sawed before the concrete has hardened, the adjacent portions of the barrier shall be supported with close fitting shields. At the present time, contraction joints are no longer required for Concrete Barrier Type 50.

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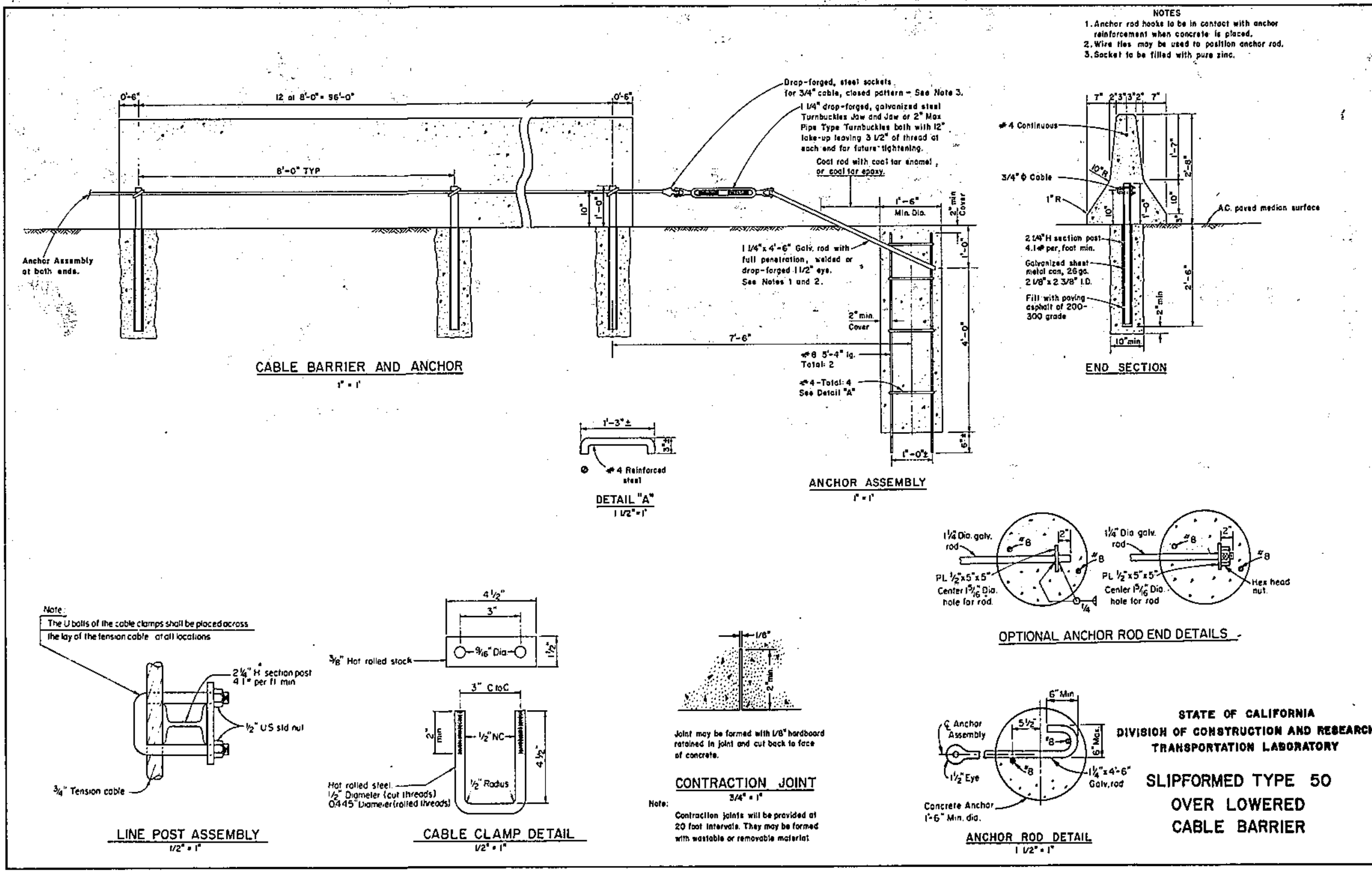

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